# Total Maximum Daily Load For Organic Enrichment and Noxious Aquatic Plants

Indian Lake
Van Buren County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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# 1. Executive Summary

Table 1. Indian Lake Summary

| | |
|---|---|
| Waterbody Name: | Indian Lake |
| County: | Van Buren |
| Use Designation Class: | A1 (primary contact recreation)<br>B(LW) (aquatic life) |
| Major River Basin: | Des Moines River Basin |
| Pollutant: | Phosphorus |
| Pollutant Sources: | Nonpoint external, atmospheric (background), and nonpoint internal (nutrient recycling) |
| Impaired Use(s): | A1 (primary contact recreation)<br>B(LW) (aquatic life) |
| 2002 303d Priority: | Low |
| Watershed Area: | 333 acres |
| Lake Area: | 51 acres |
| Lake Volume: | 250 acre-ft |
| Detention Time: | 1.2 years |
| TSI Target(s): | Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65 |
| Target Total Phosphorus Load: | See Table 2 |
| Existing Total Phosphorus Load: | 240 pounds per year |
| Load Reduction to Achieve Target: | See Table 2 |
| Wasteload Allocation | 0 |
| Load Allocation | See Table 2 |

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Indian Lake has been identified as impaired by organic enrichment and noxious aquatic plants. The purpose of the TMDL for Indian Lake is to calculate the maximum allowable nutrient loading for the lake associated with organic enrichment and noxious aquatic plant levels that will meet narrative standards and provide water quality that fully supports the lake's designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the organic enrichment and noxious aquatic plant impairments.

Phasing TMDLs is an iterative approach to managing water quality that becomes necessary when the origin, nature and sources of water quality impairments are not well understood. In Phase 1, the waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on the limited information available. A monitoring plan will be used to determine if prescribed load reductions result in attainment of water quality standards and whether or not the target values are sufficient to meet designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling.

Section 5.0 of this TMDL includes a description of planned monitoring. This TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass and Secchi depth expressed as Carlson's Trophic State

Index. Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Monitoring is essential to all TMDLs in order to:

- Assess the future beneficial use status;
- Determine if the water quality is improving, degrading or remaining status quo;
- Evaluate the effectiveness of implemented best management practices.

The additional data collected will be used to determine if the implemented TMDL and watershed management plan have been or are effective in addressing the identified water quality impairments. The data and information can also be used to determine if the TMDL has accurately identified the required components (i.e. loading/assimilative capacity, load allocations, in-lake response to pollutant loads, etc.) and if revisions are appropriate.

This TMDL has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Indian Lake, Sec. 2, T67N, R8W, 1 mile southwest of Farmington, Van Buren County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are organic enrichment and noxious aquatic plants associated with excessive nutrient loading. Designated uses for Indian Lake are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess nutrient loading has impaired aesthetic and aquatic life water quality narrative criteria (567 IAC 61.3(2)) and hindered the designated uses.

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Carlson's Trophic State Index (TSI) of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll-a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll-a and total phosphorus based on 2000 - 2003 sampling are 0.76 meters, 66 ug/L and 201 ug/L, respectively. Based on these values, the Secchi depth target has been met. Minimum in-lake reductions of 50% for chlorophyll-a and 52% for total phosphorus are required to achieve and maintain lake water quality goals and protect for beneficial uses. The estimated existing annual total phosphorus load to Indian Lake is 240 pounds per

year. The total phosphorus loading capacity for the lake based on lake response modeling is a function of the relative contribution of internal and external loads as shown in Table 2 and as described by the mathematical relationships given in Appendix E.

5. **Identification of pollution source categories** Nonpoint and atmospheric deposition (background) sources and internal recycling of phosphorus from the lake bottom sediments have been identified as the cause of impairments to Indian Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Indian Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for nonpoint sources is shown in Table 2. This includes 20 pounds per year attributable to atmospheric deposition.

Table 2. Indian Lake Total Phosphorus Loads

| Total Phosphorus Load Allocation/Target Loads (lbs/year) | | | **Required Load Reduction (lbs/year)** |
|---|---|---|---|
| **Internal** | **External** | **Total** | |
| 20 | 130 | 150 | 90 |
| 30 | 90 | 120 | 120 |
| 40 | 40 | 80 | 160 |

8. **A margin of safety:** The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased phosphorus loading was not included in this TMDL. Significant changes in the watershed land uses are unlikely. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDL.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the report.

# 2. Indian Lake, Description and History

## 2.1 The Lake

Indian Lake is located in southeast Iowa, 1 mile southwest of Farmington. Public use for Indian Lake is estimated at approximately 15,000 visitors per year. Users of the lake and of Indian Lake Park enjoy fishing, boating, camping, cross country skiing, hiking, biking, and picnicking. Although Indian Lake is designated for Primary Contact Recreation (A1), swimming is not allowed at the Lake and there is no beach. Indian Lake Park is a 177-acre park owned by the City of Farmington. The campground is located north of the lake.

Table 3. Indian Lake Features

| | |
|---|---|
| Waterbody Name: | Indian Lake |
| Hydrologic Unit Code: | HUC10 0710000910 |
| IDNR Waterbody ID: | IA 04-LDM-00150-L |
| Location: | Section 2 T67N R8W |
| Latitude: | 40° 38' N |
| Longitude: | 91° 45' W |
| Water Quality Standards Designated Uses: | 1. Primary Contact Recreation (A1)<br>2. Aquatic Life Support (B(LW)) |
| Tributaries: | Unnamed creek |
| Receiving Waterbody: | Unnamed tributary to Des Moines River |
| Lake Surface Area: | 51 acres |
| Maximum Depth: | 8 feet |
| Mean Depth: | 4.9 feet |
| Volume: | 250 acre-feet |
| Length of Shoreline: | 9,075 feet |
| Watershed Area: | 333 acres |
| Watershed/Lake Area Ratio: | 7.5:1 |
| Estimated Detention Time: | 1.2 years |

### Morphometry

Indian Lake has a mean depth of 4.9 feet and a maximum depth of 8 feet. The lake surface area is 51 acres and the storage volume is approximately 250 acre-feet. Temperature and dissolved oxygen sampling indicate that Indian Lake is relatively well mixed for most of the growing season. The lake is elongated with a shoreline development ratio of 1.7.

### Hydrology

Indian Lake is fed by an intermittent stream to the south of the lake. Indian Lake drains into an unnamed tributary of the Des Moines River. The estimated annual average detention time for Indian Lake is 1.2 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

### 2.2 The Watershed

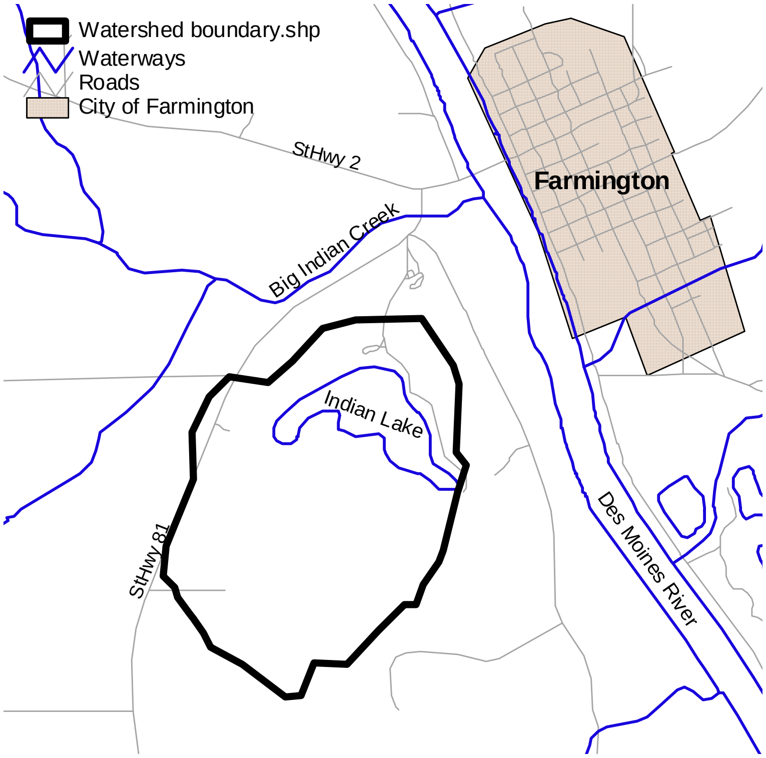
The Indian Lake watershed (Figure 1) has an area of approximately 333 acres, excluding the lake, and has a watershed to lake ratio of 7.5:1. Landuses and associated areas for the watershed in 2000 are shown in Table 4. The 2000 landuse coverages were obtained through satellite imagery. The 2000 landuse map is shown in Appendix D.

Table 4. 2000 Landuse in Indian Lake watershed

| Landuse | Area in Acres | Percent of Total Area |
|---|---|---|
| Grassland | 890 | 49 |
| Forest | 913 | 48 |
| Row Crop | 29 | 1.5 |
| Other | 29 | 1.5 |
| Total | 333 | 100 |

A field level survey of the watershed by IDNR has not been completed. There are no known animal feeding operations in the watershed. About half of the watershed is level to gently sloping (0-5%) prairie-derived soils developed from alluvium, including Colo, Zook, and Nodaway soils. The other half of the watershed has gently to strongly sloping (2-14%) prairie and forest derived soils developed from loess or pre-Wisconsin till. These soils include Grundy, Pershing, Weller, Keswick, and Lindley soils. Average rainfall in the area is 37.3 inches per year.

Figure 1. Location of Indian Lake Watershed



# 3. TMDL for Organic Enrichment and Noxious Aquatic Plants

## 3.1 Problem Identification

### Impaired Beneficial Uses and Applicable Water Quality Standards

The *Iowa Water Quality Standards* (8) list the designated uses for Indian Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1998, Indian Lake was included on the impaired water list at the recommendation of the DNR Fisheries Bureau. The impairments were due to organic enrichment and nuisance levels of algae. At that time, Class A and B uses were assessed as “partially supported.”

In 2002, the Class A and B designated uses continued to be assessed as “partially supporting” for Indian Lake. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

The impairment to Class A recreational use is the presence of aesthetically objectionable blooms of algae and nuisance algal species. The hypereutrophic conditions at Indian Lake, along with information from the IDNR Fisheries Bureau (2002 assessment cycle), suggest that the Class B(LW) aquatic life use is partially supported due to excessive nutrient loading to the water column, nuisance blooms of algae, and organic enrichment in the lake.

In 1993, flooding in the Des Moines River backed-up into Indian Lake, allowing fish like common carp, gizzard shad, bigmouth buffalo, and carpsuckers to become well established in the lake.

The aquatic community in Indian Lake has also suffered from fish kills. A winterkill occurred in the winter of 1996-97. Summer fish kills in 1997 and 1998 were associated with the decomposition of algal blooms. The kill in 1998 resulted in the loss of approximately 13,000 bluegill, 5,000 crappie, and 100 largemouth bass.

### Data Sources

Water quality surveys have been conducted on Indian Lake in 1979, 1990, and 2000-03 (1,2,3,4,5,20). Data from these surveys is available in Appendix B.

Iowa State University Lake Study data from 2000 to 2003 were evaluated for this TMDL. This study began in 2000 and ran through 2004 and approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times during the early, middle and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS.

### Interpreting Indian Lake Water Quality Data

Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 8.5:1. Data on inorganic suspended solids from the ISU sampling during 2000 - 2001 suggest that this lake is subject to moderate levels of non-algal turbidity. The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/L. The median level of inorganic suspended solids at Indian Lake during the same time period was 4.95 mg/l. The median inorganic suspended solids levels during the 2002 - 2003 sampling period remained steady at 5.00 mg/L.

Data from ISU phytoplankton sampling indicate that bluegreen algae (Cyanophyta) dominate the summertime phytoplankton community of Indian Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate a high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (37 mg/l) was the 27th highest of 131 lakes sampled. The 2001 summer average wet mass declined to 7 mg/L but still indicates that almost the entire phytoplankton community is made up of bluegreen algae throughout the growing season. Sampling for cyanobacterial toxins has not been conducted at Indian Lake for the 2000 - 2003 sampling period. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

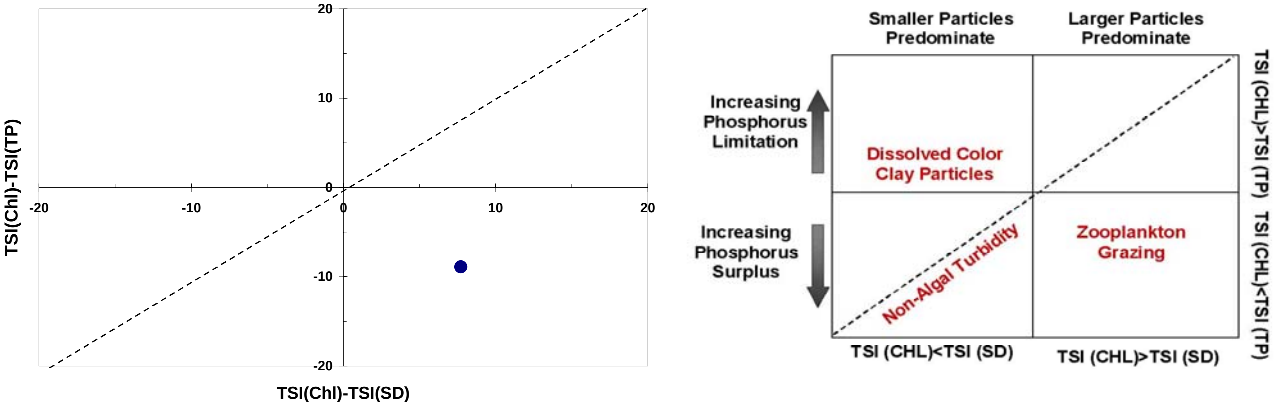
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for in-lake sampling indicate that a non-phosphorus limitation to algal growth is present (see Figure 2 and Appendix C). This non-phosphorus limitation is attributable to one or more of three factors. The relatively low nitrogen to phosphorus ratio may also impose a nitrogen limitation on algal growth during some periods. Also, zooplankton sampling data show relatively large populations of zooplankton species at this lake that graze on algae. The average summer mass of these zooplankton grazers (98 ug/l) in 2000 was the 15th highest of the 131 lakes sampled, suggesting the potential for these zooplankton grazers to limit algal production. Finally, the moderate levels of inorganic suspended solids may limit algal growth to some degree by limiting light penetration to the water column.

TSI values for 2000 - 2003 monitoring data are shown in Table 5. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 5. Indian Lake TSI Values (3,4,5,20)

| Sample Date | TSI (SD) | TSI (CHL) | TSI (TP) |
|---|---|---|---|
| 6/28/2000 | 63 | -- | 78 |
| 7/25/2000 | 67 | 58 | 86 |
| 8/16/2000 | 77 | 59 | 91 |
| 5/30/2001 | 44 | 37 | 63 |
| 6/26/2001 | 67 | 76 | 61 |
| 7/31/2001 | 77 | 80 | 87 |
| 6/4/2002 | 53 | 50 | 60 |
| 7/9/2002 | 73 | 82 | 78 |
| 8/6/2002 | 70 | 79 | 86 |
| 6/4/2003 | 70 | 58 | 82 |
| 7/9/2003 | 77 | -- | 83 |
| 8/6/2003 | 83 | 57 | 80 |

Figure 2. Indian Lake 2000 - 2003 Mean TSI Multivariate Comparison Plot (22)



## Potential Pollution Sources

Water quality in Indian Lake is influenced only by watershed nonpoint sources, atmospheric deposition, and internal recycling of pollutants from bottom sediments. There are no point source discharges in the watershed.

## Natural Background Conditions

For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature (11,17,18,19) and the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were not separated from the total nonpoint source load.

## 3.2 TMDL Target

The Phase 1 target of this TMDL is a TSI of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

Table 6. Indian Lake Existing vs. Target TSI Values

| Parameter | 2000-2003 Mean TSI | 2000-2003 Mean Value | Target TSI | Target Value | Minimum In-Lake Increase or Reduction Required |
|---|---|---|---|---|---|
| Chlorophyll | 72 | 66 ug/L | <65 | <33 ug/L | 50% Reduction |
| Secchi Depth | 64 | 0.76 meters | <65 | >0.7 meters | N/A |
| Total Phosphorus | 81 | 201 ug/L | <70 | <96 ug/L | 52% Reduction |

A second target is the attainment of aquatic life uses as measured by fishery and biological assessments. The aquatic life target for this TMDL will be achieved when the fishery of Indian Lake is determined to be fully supporting the aquatic life uses. This determination will be accomplished through an assessment conducted by the IDNR Fisheries Bureau.

### Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for organic enrichment or noxious aquatic plants. The cause of the organic enrichment and noxious aquatic plant impairments is algal blooms caused by excessive nutrient loading to the lake. The nutrient loading objective is defined by a mean total phosphorus TSI of less than 70, which is related through the Trophic State Index to chlorophyll a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the algal impairment for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

### Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. Growing season mean (GSM) in-lake total phosphorus concentrations are used to calculate an annual average total phosphorus loading.

### Modeling Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (10) was calculated. The results from both approaches were compared to select the best-fit empirical model.

Table 7. Model Results

| Model | Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 201 ug/L, SPO TP = 122 ug/L | Comments |
|---|---|---|
| Loading Function | 620 | Reckhow (10) |
| EPA Export | 160 | EPA/5-80-011 (21) |
| WILMS Export | 90 | "most likely" export coefficients |
| Reckhow 1991 EUTROMOD Equation | 45,480 | GSM model. |
| Canfield-Bachmann 1981 Natural Lake | 610 | GSM model. |
| Canfield-Bachmann 1981 Artificial Lake | 1,640 | GSM model. |
| Reckhow 1977 Anoxic Lake | 150 | GSM model. |
| Reckhow 1979 Natural Lake | 1,200 | GSM model. P out of range |
| Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr) | 330 | GSM model. Pin/P out of range |
| Nurnberg 1984 Oxic Lake | 160 (internal load = 80) | Annual model. P out of range |
| Walker 1977 General Lake | 130 | SPO model. |
| Vollenweider 1982 Combined OECD | 450 | Annual model. |
| Vollenweider 1982 Shallow Lake | 480 | Annual model. |

The Canfield-Bachmann Natural Lake, Reckhow Anoxic, Reckhow Oxic, Walker, Nurnberg and Vollenweider models (9) all resulted in values within the range of the Loading Function and export estimates. Due to the lack of a current field assessment and corresponding practice factors for the land uses in the watershed, statewide RUSLE coverages were used to determine gross potential soil loss for use in the Loading Function estimate of sediment-attached delivery of phosphorus. Based on this and comparison of the Loading Function model with the export estimates, it was felt that the Loading Function was significantly overestimating sediment-attached delivery of phosphorus to the lake and a comparison based on the export estimates was warranted.

The Reckhow Anoxic, Nurnberg and Walker models were closest to the export estimates. Dissolved oxygen sampling at the maximum depth location in Indian Lake shows that while the lake does weakly stratify, anoxia is limited, making application of the Reckhow Anoxic Model questionable. The Walker Model is a Spring Overturn (SPO) model. The available in-lake phosphorus monitoring for Indian Lake corresponds with the growing season, requiring late spring or early summer sampling values to be used as a surrogate for the early spring phosphorus values used to derive the Walker Model.

The model results and the high phosphorus levels at Indian Lake indicate the likelihood of a significant internal loading. The existing load predicted by the Nurnberg Model also indicates a significant internal load. Therefore, use of the EPA export coefficients with the Nurnberg Oxic Lake Model was selected as the basis for determining the existing load. The Nurnberg Model was also used to determine load targets as a function of the relative contribution from internal and external sources.

The equation for the Nurnberg Oxic Lake Model is:

$$P = \frac{L_{Ext}}{q_s}(1-R) + \frac{L_{Int}}{q_s}$$

where:

$$R = \frac{15}{18+q_s}$$

$P =$ predicted in-lake total phosphorus concentration (ug/L)
$L_{Ext} =$ external areal total phosphorus load (mg/m$^2$ of lake area per year)
$L_{Int} =$ internal areal total phosphorus load (mg/m$^2$ of lake area per year)
$q_s =$ areal water loading (m/yr)

The Nurnberg Model represents a possible continuum of internal and external loads for a given in-lake total phosphorus concentration. The EPA Export external load estimate was used in combination with the Nurnberg Model to determine the existing loads as follows:

$$P = 201(\mu g/L) = \frac{342(mg/m^2)}{1.23(m/yr)}(1-\frac{15}{18+1.23(m/yr)}) + \frac{172(mg/m^2)}{1.23(m/yr)}$$

An example of a load calculation for target internal and external loads of 20 and 130 pounds, respectively, is:

$$P = 87(\mu g / L) = \frac{285(mg / m^2)}{1.23(m / yr)}(1 - \frac{15}{18 + 1.23(m / yr)}) + \frac{43.6(mg / m^2)}{1.23(m / yr)}$$

The above calculation includes a margin of safety by using an in-lake concentration 10% below the desired endpoint (P < 96 ug/L) to calculate the target loads. The annual total phosphorus loads are obtained by multiplying the areal loads ($L_{Ext}$, $L_{Int}$) by the lake area in square meters and converting the resulting values from milligrams to pounds.

For the in-lake total phosphorus target and any selected target internal load, the corresponding target external load, target total load or target load reduction can be calculated from the relationships shown in Figures E-1 through E-3 in Appendix E.

### Waterbody Pollutant Loading Capacity

The chlorophyll a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Indian Lake can receive and meet its designated uses. The Phase 1 target TSI (TP) value is less than 70, corresponding with an in-lake total phosphorus concentration of less than 96 ug/L. For the selected lake response model, the target total load is a function of the relative internal and external load contributions as shown in Table 8.

Table 8. Indian Lake Total Phosphorus Target

| Total Phosphorus Target Loads (lbs/year) | | |
|---|---|---|
| **Internal** | **External** | **Total** |
| 20 | 130 | 150 |
| 30 | 90 | 120 |
| 40 | 40 | 80 |

## 3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Indian Lake in this TMDL. The first is the phosphorus load from the watershed that drains directly into the lake. The second source is internal phosphorus loading from sediments. The third source is atmospheric deposition. Note that load contributions from groundwater influx have not been separated from the total nonpoint source loads.

### Existing Load

The annual total phosphorus load to Indian Lake is estimated to be 240 pounds per year based on the EPA export coefficients and the Nurnberg Oxic Lake model. This estimate includes 140 pounds per year from external nonpoint sources in the watershed, 80 pounds per year attributable to internal loading, and 20 pounds per year from atmospheric deposition.

## Departure from Load Capacity

Table 9 shows the load reductions necessary to achieve and maintain Phase 1 water quality goals.

Table 9. Indian Lake Load Reductions to Meet Phase 1 Goals

| Total Phosphorus Loads (lbs/year) | | **Required Load Reduction (lbs/year)** |
|---|---|---|
| **Internal** | **External** | |
| 20 | 130 | 90 |
| 30 | 90 | 120 |
| 40 | 40 | 160 |

## Identification of Pollutant Sources

There are no point source discharges in the Indian Lake watershed. From the EPA export coefficients, the most external nonpoint source phosphorus delivered to the lake is from grassland landuse as shown in Figure 3. It should be noted that while the export coefficients provide estimates of the primary potential pollutant sources and a means of estimating existing internal versus external loads, the existing and target total loads identified in this TMDL are independent of the estimated watershed load. The export estimate was used only for comparison purposes to select an empirical lake response model and to separate the existing total load predicted by the lake response model into internal and external components. Existing and target loads were calculated from measured and target in-lake total phosphorus concentrations using the selected lake response model as shown in *Section 3.2, Modeling Approach.* Also, the watershed estimates include only external watershed phosphorus inputs and do not account for internal loading.

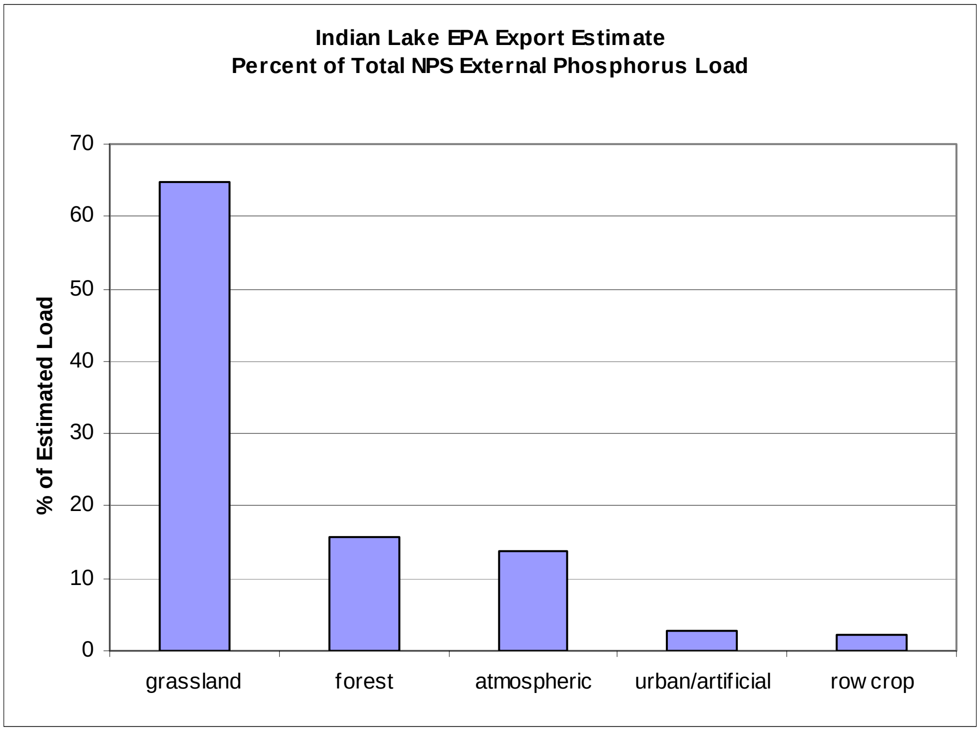
The Nurnberg Model indicates that internal loading makes up approximately 33% of the existing total phosphorus mass loading to the lake. However, the internal load has a much greater effect on in-lake total phosphorus concentrations on a pound for pound basis. The model relationship shows that one pound of internal loading is equivalent to 4.5 pounds of external loading. In terms of lake response, the internal load is estimated to comprise approximately 69% of the total load.

Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites, individual residences, and seasonal-use businesses and housing units. Manure and waste from wildlife, pets, fish cleaning stations, and etc. also contribute to the phosphorus loading. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase II of this TMDL.

## Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Indian Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contributions to Indian Lake must be reduced as shown in Table 9 (above).

Figure 3. EPA Export Estimate External Nonpoint Source Contributions



## 3.4 Pollutant Allocation

### Wasteload Allocation

Since there are no phosphorus point source contributors in the Indian Lake watershed, the Waste Load Allocation (WLA) is zero pounds per year.

### Load Allocation

Table 10 shows the Load Allocation (LA) for this TMDL based on varying internal and external load contributions. The external and total loads include 20 pounds per year from atmospheric deposition.

Table 10. Indian Lake Load Allocation

| Total Phosphorus Load Allocation (lbs/year) | | |
|---|---|---|
| **Internal** | **External** | **Total** |
| 20 | 130 | 150 |
| 30 | 90 | 120 |
| 40 | 40 | 80 |

### Margin of Safety

The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction will result in the attainment of water quality targets.

## 4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Indian Lake water quality.

The estimated existing phosphorus loading from watershed sources is approximately 0.4 pounds/year/acre. The internal recycling load estimated for this lake is significant, and for a large reduction in internal loading (82%) the selected lake response model indicates that the target phosphorus level could be achieved while maintaining the existing external load. However, such a large reduction in internal loading could be difficult to achieve, and it is recommended that practices which will reduce both internal and external loads to the lake be implemented. Because reductions in internal recycling and watershed loading will require management practices that take time to implement, the following timetable is suggested for improvements:

- Reduce watershed and recycle loading from 240 pounds per year to 200 pounds per year by 2010.
- Reduce watershed and recycle loading from 200 pounds per year to 160 pounds per year by 2015.
- Reduce watershed and recycle loading from 160 pounds per year to 120 pounds per year by 2020.

The final target of 120 pounds per year assumes that reductions in internal and external loads will be roughly proportional. It should be noted that the final total target load may vary depending upon the internal and external load reductions achieved as shown in previous sections of this report.

The watershed loading estimate from EPA export coefficients (Figure 3) indicates that the majority of the external phosphorus load to Indian Lake originates on grassland and forest land uses.

The following best management practices would be beneficial for reducing external nutrient (phosphorous) delivery to Indian Lake:

- Manage agricultural soils for the optimum soil test category. This soil test category is the most profitable for producers to sustain in the long term.
- Minimize the potential losses of applied phosphorus by incorporating or subsurface applying the fertilizer or manure and avoiding late fall or winter applications.
- Maintain or improve forestry management practices to improve water infiltration.
- Encourage the adoption of management intensive grazing systems on the existing pastureland.
- Identify key locations in the watershed and construct wetlands or grade stabilization structures to settle out adsorbed and dissolved phosphorus in surface runoff.
- Through incentives and existing programs, reduce runoff volume and/or velocity through the strategic location of contour grass buffer strips and riparian buffer strips, etc.

The internal nutrient component of Indian Lake may be due in part to resuspension of bottom sediments by wind and wave action. The lake does weakly stratify at the maximum depth sampling location but remains relatively well mixed above the mean depth. Increasing the mean depth to at least 3 meters would allow the lake to stratify, reducing the internal mixing. Lakes that stratify only mix with the spring and fall overturn. The net result is less phosphorus available in the water column during the growing season when it could be used for algal production.

In addition to wind and wave action, a large rough fish population comprised of common carp degrade water quality by eliminating aquatic macrophytes that take up available nutrients and by stirring up bottom sediments aiding in sediment and nutrient resuspension. A complete chemical renovation of the lake fishery is a management option for consideration in the future. Additional management practices to reduce internal loading include riprap along the shoreline to reduce shoreline erosion, and dredging to remove nutrients from the lake system.

## 5. Monitoring

Further monitoring is needed at Indian Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum data requirements established by Iowa’s 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Indian Lake has been included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy. The TMDL program is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

The phosphorus load due to internal recycling is estimated by the selected lake response model but due to uncertainty inherent in the available data and model predictions further investigation is warranted. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes. When a protocol for measuring phosphorus flux becomes available, sampling will be done for this lake and the recycling load component estimate will be further refined.

## 6. Public Participation

The draft TMDL was presented at a public meeting in Farmington, Iowa on December 13, 2004. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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# 8. Appendix A - Lake Hydrology

## General Methodology

Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi$^2$ to 195 mi$^2$ with mean and median values of 10 mi$^2$ and 3.5 mi$^2$, respectively. Few, if any, of these lakes have gauging data available to determine flow statistics for the tributaries that feed into them. A select few have some type of stage information that may be useful in determining historical discharge from the lake itself.

With the large number of lakes on the State's 303(d) list and the requirement for rapid development of TMDLs for these lakes, it was realized that a method to quickly estimate flow statistics for required lake response model inputs would be desirable. In an attempt to achieve this goal, flow data and watershed characteristics for a number of USGS gauging stations with small contributing watershed areas were compiled and evaluated via both simple and multiple linear regressions. The primary focus of this evaluation was estimation of the average annual flow statistic for input to empirical lake response models. However, regression equations for monthly average and calendar year flow statistics were also developed that may be of additional use.

It should be noted that attempts were made to develop regression equations for low-flow streamflow statistics (1Q10, 7Q10, 30Q10, 30Q5 and harmonic mean) but the relationships derived were for the most part considered too weak (R^2 adj.< 70%) to be of practical use. One exception to this is the 30Q5 statistic, which gave an R^2 adj. of 85%. In addition, regression equations were developed for monthly flow prediction models for two months (January and May). Once again, the relationships did not exhibit a high level of correlation and due to the large amount of data required to develop these models, development of equations for additional months was not attempted.

Data

Flow data and watershed characteristics from 26 USGS gauging stations were used to derive the regression equations. The ranges of basin characteristics used to develop the regression equations are shown in Table A-1.

Drainage areas were taken directly from USGS gauge information available at http://water.usgs.gov/waterwatch/ . Precipitation values were obtained through the Iowa Environmental Mesonet IEM Climodat Interface at http://mesonet.agron.iastate.edu/climodat/index.phtml . Where weather and gauging stations were not located in the same town, precipitation information was obtained from the weather station located in the town with the shortest straight-line distance from the gauging station.

Average basin slope and land cover percentages were determined using Arc View and statewide coverages clipped within HUC-12 sub-watersheds. It should be noted that the smallest basin coverages used in determining land cover percentages and average basin slopes were single HUC-12 units (i.e. no attempt was made to subdivide HUC-12 basins into smaller units where the drainage area was less than the area of the HUC-12 basin). Therefore, the regression models assume that for very small watersheds the land cover percentages of the HUC-12 basin are representative of the watershed located within the basin.

The Hydrologic Region for each station was determined from Figure 1 of USGS Water-Resources Investigation Report 87-4132, Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa. None of the stations included in the analyses were located in Regions 1 or 5. This is reflected in the regression equations developed that utilize the hydrologic region as a variable.

Table A-1. Ranges of Basin Characteristics Used to Develop the Regression Equations

| Basin Characteristic | Name in equations | Minimum | Mean | Maximum |
|---|---|---|---|---|
| Drainage Area ($mi^2$) | DA | 2.94 | 80.7 | 204 |
| Mean Annual Precip (inches) | $\overline{P}_A$ | 26.0 | 34.0 | 36.2 |
| Average Basin Slope (%) | S | 1.53 | 4.89 | 10.9 |
| Landcover - % Water | W | 0.020 | 0.336 | 2.80 |
| Landcover - % Forest | F | 2.45 | 10.3 | 29.9 |
| Landcover - % Grass/Hay | G | 9.91 | 31.3 | 58.7 |
| Landcover - % Corn | C | 6.71 | 31.9 | 52.3 |
| Landcover - % Beans | B | 6.01 | 23.1 | 37.0 |
| Landcover - % Urban/Artificial | U | 0 | 2.29 | 7.26 |
| Landcover - % Barren/Sparse | $B'$ | 0 | 0.322 | 2.67 |
| Hydrologic Region | H | Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only. | | |

Methods

Simple regression models were developed for annual average and monthly average statistics with drainage area as the sole explanatory variable. Multiple linear regression models considering all explanatory variables were developed utilizing stepwise regression in Minitab. All data with the exception of the Hydrologic Region were log transformed. Explanatory variables with regression coefficients that were not statistically different from zero (p-value greater than 0.05) were not utilized.

## Equation Variables

Table A-2. Regression Equation Variables

| | |
|---|---|
| Annual Average Flow (cfs) | $\overline{Q}_A$ |
| Monthly Average Flow (cfs) | $\overline{Q}_{MONTH}$ |
| Annual Flow – calendar year (cfs) | $Q_{YEAR}$ |
| Drainage Area (mi$^2$) | DA |
| Mean Annual Precip (inches) | $\overline{P}_A$ |
| Mean Monthly Precip (inches) | $\overline{P}_{MONTH}$ |
| Antecedent Mean Monthly Precip (inches) | $\overline{A}_{MONTH}$ |
| Annual Precip – calendar year (inches) | $P_{YEAR}$ |
| Antecedent Precip – calendar year (inches) | $A_{YEAR}$ |
| Average Basin Slope (%) | S |
| Landcover - % Water | W |
| Landcover - % Forest | F |
| Landcover - % Grass/Hay | G |
| Landcover - % Corn | C |
| Landcover - % Beans | B |
| Landcover - % Urban/Artificial | U |
| Landcover - % Barren/Sparse | $B'$ |
| Hydrologic Region | H |

## Equations

Table A-3. Drainage Area Only Equations

| **Equation** | **R$^2$ adjusted (%)** | **PRESS (log transform)** |
|---|---|---|
| $\overline{Q}_A = 0.832DA^{0.955}$ | 96.1 | 0.207290 |
| $\overline{Q}_{JAN} = 0.312DA^{0.950}$ | 85.0 | 0.968253 |
| $\overline{Q}_{FEB} = 1.32DA^{0.838}$ | 90.7 | 0.419138 |
| $\overline{Q}_{MAR} = 0.907DA^{1.03}$ | 96.6 | 0.220384 |
| $\overline{Q}_{APR} = 0.983DA^{1.02}$ | 93.1 | 0.463554 |
| $\overline{Q}_{MAY} = 1.97DA^{0.906}$ | 89.0 | 0.603766 |
| $\overline{Q}_{JUN} = 2.01DA^{0.878}$ | 88.9 | 0.572863 |
| $\overline{Q}_{JUL} = 0.822DA^{0.977}$ | 87.2 | 0.803808 |
| $\overline{Q}_{AUG} = 0.537DA^{0.914}$ | 74.0 | 1.69929 |
| $\overline{Q}_{SEP} = 0.123DA^{1.21}$ | 78.7 | 2.64993 |
| $\overline{Q}_{OCT} = 0.284DA^{1.04}$ | 90.2 | 0.713257 |
| $\overline{Q}_{NOV} = 0.340DA^{0.999}$ | 89.8 | 0.697353 |
| $\overline{Q}_{DEC} = 0.271DA^{1.00}$ | 86.3 | 1.02455 |

Table A-4. Multiple Regression Equations

| **Equation** | **$R^2$ adjusted (%)** | **PRESS (log transform)** |
|---|---|---|
| $\overline{Q}_A = 1.17\times10^{-3}DA^{0.998}\overline{P}_A^{\,1.54}S^{-0.261}(1+F)^{0.249}C^{0.230}$ | 98.7 | 0.177268 (n=26) |
| $\overline{Q}_{JAN} = 0.213DA^{0.997}\overline{A}_{JAN}^{\,0.949}$ | 89.0 | 0.729610 (n=26;same for all $\overline{Q}_{MONTH}$ ) |
| $\overline{Q}_{FEB} = 2.98DA^{0.955}\overline{A}_{FEB}^{\,0.648}G^{-0.594}(1+F)^{0.324}$ | 97.0 | 0.07089 |
| $\overline{Q}_{MAR} = 6.19DA^{1.10}B^{-0.386}G^{-0.296}$ | 97.8 | 0.07276 |
| $\overline{Q}_{APR} = 1.24DA^{1.09}\overline{A}_{APR}^{\,1.64}S^{-0.311}B^{-0.443}$ | 97.1 | 0.257064 |
| $\overline{Q}_{MAY} = 10^{(-3.03+0.114H)}DA^{0.846}\overline{P}_A^{\,2.05}$<br>Hydrologic Regions 2, 3 & 4 Only | 92.1 | 0.958859 |
| $\overline{Q}_{MAY} = 1.86\times10^{-3}DA^{0.903}\overline{P}_A^{\,1.98}$ | 90.5 | 1.07231 |
| $\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)}DA^{0.891}C^{0.404}\overline{P}_{JUN}^{\,1.84}(1+F)^{0.326}G^{-0.387}$<br>Hydrologic Regions 2, 3 & 4 Only | 97.0 | 0.193715 |
| $\overline{Q}_{JUN} = 8.13\times10^{-3}DA^{0.828}C^{0.478}\overline{P}_{JUN}^{\,2.70}$ | 95.9 | 0.256941 |
| $\overline{Q}_{JUL} = 1.78\times10^{-3}DA^{0.923}\overline{A}_{JUL}^{\,4.19}$ | 91.7 | 0.542940 |
| $\overline{Q}_{AUG} = 4.17\times10^{7}DA^{0.981}(1+B')^{-1.64}(1+U)^{0.692}\overline{P}_A^{\,-7.2}\overline{A}_{AUG}^{\,4.59}$ | 90.4 | 1.11413 |
| $\overline{Q}_{SEP} = 1.63DA^{1.39}B^{-1.08}$ | 86.9 | 1.53072 |
| $\overline{Q}_{OCT} = 5.98DA^{1.14}B^{-0.755}S^{-0.688}(1+B')^{-0.481}$ | 95.7 | 0.375296 |
| $\overline{Q}_{NOV} = 5.79DA^{1.17}B^{-0.701}G^{-0.463}(1+U)^{0.267}(1+B')^{-0.397}$ | 95.1 | 0.492686 |
| $\overline{Q}_{DEC} = 0.785DA^{1.18}B^{-0.654}(1+U)^{0.331}(1+B')^{-0.490}$ | 92.4 | 0.590576 |
| $Q_{YEAR} = 3.164\times10^{-4}DA^{0.942}P_{YEAR}^{\,2.39}A_{YEAR}^{\,1.02}S^{-0.206}\overline{P}_A^{\,1.27}C^{0.121}(1+U)^{0.0966}$ | 83.9 | 32.6357 (n=716) |

## General Application

In general, the regression equations developed using multiple watershed characteristics will be better predictors than those using drainage area as the sole explanatory variable. The single exception to this appears to be for the May Average Flow worksheet where the PRESS statistic values indicate that use of drainage area alone results in the least error in the prediction of future observations.

Although 2002 land cover grids for the state are now available with 19 different classifications, the older 2000 land cover grids with 9 different classifications were used in developing the regression equations. The 2000 land cover grids should be used in development of flow estimates using the equations.

The equations were developed from stream gauge data for watersheds with relatively minor open water surface percentages relative to other types of land cover (see Table A-1). For application to lake watersheds, particularly those with small watershed/lake area ratios, the basin slope and land cover percentages taken from HUC-12 basins may need to be adjusted so that the hydraulic budget components of surface inflow and direct precipitation on the lake itself can be treated separately. One method of accomplishing this is by subtraction of lake water surface acreage from the total land cover and slope (lakes will have 0% slope) acreages and recalculation of the % coverages. The watershed (drainage) area used in the equations should not include the area of the lake surface.

### Application to Indian Lake - Calculations

Table A-5. Indian Lake Hydrology Calculations

| | | |
|---|---|---|
| Lake | Indian Lake | |
| Type | Impoundment | |
| Inlet(s) | unnamed creek | |
| Outlet(s) | unnamed tributary to Des Moines River | |
| Volume | 250 | (acre-ft) |
| Lake Area | 51 | (acres) |
| Mean Depth | 4.86 | (ft) |
| Drainage Area | 332 | (acres) |
| Mean Annual Precip | 37.3 | (inches) |
| Average Basin Slope | 5.46 | (%) |
| %Water | 0.00 | |
| %Forest | 51.15 | |
| %Grass/Hay | 45.11 | |
| %Corn | 0.85 | |
| %Beans | 0.99 | |
| %Urban/Artificial | 1.31 | |
| %Barren/Sparse | 0.59 | |
| Hydrologic Region | 3 | |
| Mean Annual Class A Pan Evap | 47.00 | (inches) |
| Mean Annual Lake Evap | 34.78 | (inches) |
| Est. Annual Average Inflow | 196.31 | (acre-ft) |
| Direct Lake Precip | 159.86 | (acre-ft/yr) |
| Est. Annual Average Det. Time (inflow + precip) | 0.7019 | (yr) |
| Est. Annual Average Det. Time (outflow) | 1.2071 | (yr) |

# 9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (1)

| **Parameter** | **7/5/1979** | **8/8/1979** | **9/6/1979** |
|---|---|---|---|
| Secchi Depth (m) | 0.55 | 0.85 | 0.65 |
| Chlorophyll (ug/L) | 8.5 | 19 | 35 |
| $NO_3$+$NO_2$-N (mg/L) | -- | -- | 0.05 |
| Total Phosphorus (ug/l as P) | 70 | 44 | 59 |
| Alkalinity (mg/L) | 93 | 90 | 87 |

Data above is averaged over the upper 3 feet.

Table B-2. Data collected in 1990 by Iowa State University (2)

| **Parameter** | **5/18/1990** | **6/23/1990** | **7/21/1990** |
|---|---|---|---|
| Secchi Depth (m) | 0.7 | 0.5 | 1.9 |
| Chlorophyll (ug/L) | 88.7 | 53.5 | 5.6 |
| Total Nitrogen (mg/L as N) | 2.1 | 2.4 | 1.2 |
| Total Phosphorus (ug/l as P) | 206.5 | 162.4 | 128.7 |
| Total Suspended Solids (mg/L) | 21.9 | 14.4 | 5.7 |
| Inorganic Suspended Solids (mg/L) | 0 | 7 | 2.2 |

Data above is for surface depth.

Table B-3. Data collected in 2000 by Iowa State University (3)

| **Parameter** | **6/28/2000** | **7/25/2000** | **8/15/2000** |
|---|---|---|---|
| Secchi Depth (m) | 0.8 | 0.6 | 0.3 |
| Chlorophyll (ug/L) | -- | 15.8 | 17.5 |
| $NH_3$+$NH_4^+$ -N (ug/L) | -- | -- | -- |
| $NH_3$ –N (un-ionized) (ug/L) | -- | -- | -- |
| $NO_3$+$NO_2$-N (mg/L) | 0.17 | 0.11 | 0.09 |
| Total Nitrogen (mg/L as N) | 1.28 | 1.19 | 2.35 |
| Total Phosphorus (ug/l as P) | 226 | 292 | 399 |
| Silica (mg/L as $SiO_2$) | -- | -- | -- |
| pH | 6.8 | 7.5 | 7.5 |
| Alkalinity (mg/L) | 271 | 106 | 96 |
| Total Suspended Solids (mg/L) | 9 | 8 | 12 |
| Inorganic Suspended Solids (mg/L) | 5 | 4 | 6 |
| Volatile Suspended Solids (mg/L) | 4 | 4 | 6 |

Table B-4. Data collected in 2001 by Iowa State University (4)

| **Parameter** | **5/30/2001** | **6/26/2001** | **7/31/2001** |
|---|---|---|---|
| Secchi Depth (m) | 3.0 | 0.6 | 0.3 |
| Chlorophyll (ug/L) | 1.8 | 100.4 | 160.1 |
| $NH_3$+$NH_4^+$ -N (ug/L) | -- | -- | -- |
| $NH_3$ –N (un-ionized) (ug/L) | -- | -- | -- |
| $NO_3$+$NO_2$-N (mg/L) | <0.07 | <0.07 | 0.29 |
| Total Nitrogen (mg/L as N) | 3.49 | 3.20 | 3.45 |
| Total Phosphorus (ug/l as P) | 185 | 108 | 98 |
| Silica (mg/L as $SiO_2$) | -- | -- | -- |
| pH | 7.8 | 8.8 | 8.9 |
| Alkalinity (mg/L) | 113 | 91 | 81 |
| Total Suspended Solids (mg/L) | 2 | 16 | 12 |
| Inorganic Suspended Solids (mg/L) | 2 | 5 | 7 |
| Volatile Suspended Solids (mg/L) | <1 | 12 | 5 |

Table B-5. Data collected in 2002 by Iowa State University (5)

| **Parameter** | **6/4/2002** | **7/9/2002** | **8/6/2002** |
|---|---|---|---|
| Secchi Depth (m) | 1.6 | 0.4 | 0.5 |
| Chlorophyll (ug/L) | 7.0 | 188.2 | 136.1 |
| $NH_3$+$NH_4^+$ -N (ug/L) | 183 | 265 | 303 |
| $NH_3$ –N (un-ionized) (ug/L) | 16 | 200 | 218 |
| $NO_3$+$NO_2$-N (mg/L) | 0.11 | 0.17 | 0.08 |
| Total Nitrogen (mg/L as N) | 0.81 | 1.77 | 1.78 |
| Total Phosphorus (ug/l as P) | 48 | 166 | 281 |
| Silica (mg/L as $SiO_2$) | 4.08 | 9.06 | 8.44 |
| pH | 8.1 | 9.5 | 9.5 |
| Alkalinity (mg/L) | 126 | 76 | 82 |
| Total Suspended Solids (mg/L) | 10 | 9 | 16 |
| Inorganic Suspended Solids (mg/L) | 5 | -- | 2 |
| Volatile Suspended Solids (mg/L) | 5 | -- | 14 |

Table B-6. Data collected in 2003 by Iowa State University (20)

| **Parameter** | **6/4/2003** | **7/9/2003** | **8/6/2003** |
|---|---|---|---|
| Secchi Depth (m) | 0.5 | 0.3 | 0.2 |
| Chlorophyll (ug/L) | 17.0 | -- | 14.8 |
| $NH_3$+$NH_4^+$ -N (ug/L) | 346 | 746 | 201 |
| $NH_3$ –N (un-ionized) (ug/L) | 16 | 22 | 102 |
| $NO_3$+$NO_2$-N (mg/L) | 0.09 | 0.14 | 0.17 |
| Total Nitrogen (mg/L as N) | 1.71 | 1.49 | 2.36 |
| Total Phosphorus (ug/l as P) | 215 | 235 | 191 |
| Silica (mg/L as $SiO_2$) | 7.04 | 9.24 | 7.46 |
| pH | 8.1 | 7.7 | 9.2 |
| Alkalinity (mg/L) | 85 | 54 | 52 |
| Total Suspended Solids (mg/L) | 16 | 30 | 26 |
| Inorganic Suspended Solids (mg/L) | 7 | 20 | 5 |
| Volatile Suspended Solids (mg/L) | 8 | 10 | 21 |

Table B-7. 2000 Phytoplankton Data (3)

| | **6/28/2000** | **7/25/2000** | **8/15/2000** |
|---|---|---|---|
| **Division** | **Wet Mass (mg/L)** | **Wet Mass (mg/L)** | **Wet Mass (mg/L)** |
| Cyanophyta | 6.7E+01 | 3.3E+01 | 1.0E+01 |
| Cryptophyta | 1.1E-01 | 5.3E-01 | 0.0E+00 |
| Chlorophyta | 8.1E-01 | 0.0E+00 | 0.0E+00 |
| Dinophyta | 0.0E+00 | 1.1E+00 | 0.0E+00 |
| Chrysophyta | 0.0E+00 | 2.7E-01 | 0.0E+00 |
| Euglenophyta | 1.7E-01 | 3.8E-01 | 0.0E+00 |
| **TOTAL** | **6.8E+01** | **3.5E+01** | **1.0E+01** |

Table B-8.  2001 Phytoplankton Data (4)

| | **5/30/2001** | **6/26/2001** | **7/31/2001** |
|---|---|---|---|
| **Division** | **Wet Mass (mg/L)** | **Wet Mass (mg/L)** | **Wet Mass (mg/L)** |
| Chlorophyta | 0.0E+00 | 6.5E-02 | 0.0E+00 |
| Chrysophyta | 0.0E-02 | 0.0E+00 | 0.0E+00 |
| Cryptophyta | 2.2E-02 | 2.3E-01 | 0.0E+00 |
| Cyanobacteria | 3.5E-02 | 1.8E+01 | 4.1E+00 |
| Dinophyta | 1.2E-01 | 0.0E+00 | 0.0E+00 |
| Euglenophyta | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| **Total** | **1.8E-01** | **1.9E+01** | **4.1E+00** |

Additional lake sampling results and information can be viewed at:
http://limnology.eeob.iastate.edu/

# 10. Appendix C - Trophic State Index

## Carlson's Trophic State Index

Carlson's Trophic State Index is a numeric indicator of the continuum of the biomass of suspended algae in lakes and thus reflects a lake's nutrient condition and water transparency. The level of plant biomass is estimated by calculating the TSI value for chlorophyll-a. TSI values for total phosphorus and Secchi depth serve as surrogate measures of the TSI value for chlorophyll.

The TSI equations for total phosphorus, chlorophyll and Secchi depth are:

$$\mathrm{TSI\ (TP)} = 14.42 \ln(\mathrm{TP}) + 4.15$$

$$\mathrm{TSI\ (CHL)} = 9.81 \ln(\mathrm{CHL}) + 30.6$$

$$\mathrm{TSI\ (SD)} = 60 - 14.41 \ln(\mathrm{SD})$$

TP = in-lake total phosphorus concentration, ug/L

CHL = in-lake chlorophyll-a concentration, ug/L

SD = lake Secchi depth, meters

The three index variables are related by linear regression models and *should* produce the same index value for a given combination of variable values. Therefore, any of the three variables can theoretically be used to classify a waterbody.

Table C-1. Changes in temperate lake attributes according to trophic state (modified from 22,23,24).

| TSI Value | Attributes | Primary Contact Recreation | Aquatic Life (Fisheries) |
|---|---|---|---|
| 50-60 | eutrophy: anoxic hypolimnia; macrophyte problems possible | [none] | warm water fisheries only; percid fishery; bass may be dominant |
| 60-70 | blue green algae dominate; algal scums and macrophyte problems occur | weeds, algal scums, and low transparency discourage swimming and boating | Centrarchid fishery |
| 70-80 | hyper-eutrophy (light limited). Dense algae and macrophytes | weeds, algal scums, and low transparency discourage swimming and boating | Cyprinid fishery (e.g., common carp and other rough fish) |
| >80 | algal scums; few macrophytes | algal scums, and low transparency discourage swimming and boating | rough fish dominate; summer fish kills possible |

Table C-2. Summary of ranges of TSI values and measurements for chlorophyll-a and Secchi depth used to define Section 305(b) use support categories for the 2004 reporting cycle.

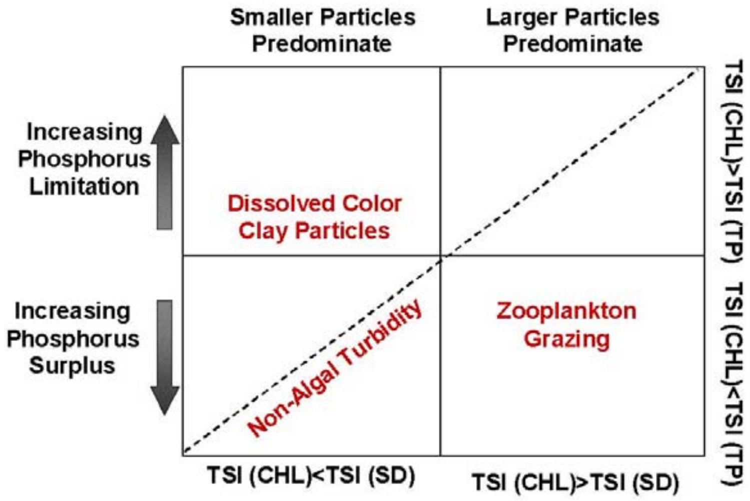
| Level of Support | TSI value | Chlorophyll-a (ug/l) | Secchi Depth (m) |
|---|---|---|---|
| ***fully supported*** | <=55 | *<=12* | *>1.4* |
| ***fully supported / threatened*** | 55 → 65 | *12 → 33* | *1.4 → 0.7* |
| ***partially supported***<br>(evaluated: in need of further investigation) | 65 → 70 | *33 → 55* | *0.7 → 0.5* |
| ***partially supported***<br>(monitored: candidates for Section 303(d) listing) | 65-70 | *33 → 55* | *0.7→ 0. 5* |
| ***not supported***<br>(monitored or evaluated: candidates for Section 303(d) listing) | >70 | *>55* | *<0.5* |

Table C-3. Descriptions of TSI ranges for Secchi depth, phosphorus, and chlorophyll-a for Iowa lakes.

| TSI value | Secchi description | Secchi depth (m) | Phosphorus & Chlorophyll-a description | Phosphorus levels (ug/l) | Chlorophyll-a levels (ug/l) |
|---|---|---|---|---|---|
| > 75 | extremely poor | < 0.35 | extremely high | > 136 | > 92 |
| 70-75 | very poor | 0.5 – 0.35 | very high | 96 - 136 | 55 – 92 |
| 65-70 | poor | 0.71 – 0.5 | high | 68 – 96 | 33 – 55 |
| 60-65 | moderately poor | 1.0 – 0.71 | moderately high | 48 – 68 | 20 – 33 |
| 55-60 | relatively good | 1.41 – 1.0 | relatively low | 34 – 48 | 12 – 20 |
| 50-55 | very good | 2.0 – 1.41 | low | 24 – 34 | 7 – 12 |
| < 50 | exceptional | > 2.0 | extremely low | < 24 | < 7 |

The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential relationships as shown in Figure C-1.

Figure C-1.  Multivariate TSI Comparison Chart (7)



## Indian Lake TSI Values

Table C-4.  1979 Indian TSI Values (1)

| Sample Date | TSI (SD) | TSI (CHL) | TSI (TP) |
|---|---|---|---|
| 7/5/1979 | 69 | 52 | 65 |
| 8/8/1979 | 62 | 59 | 59 |
| 9/6/1979 | 66 | 65 | 63 |

Table C-5.  1990 Indian TSI Values (2)

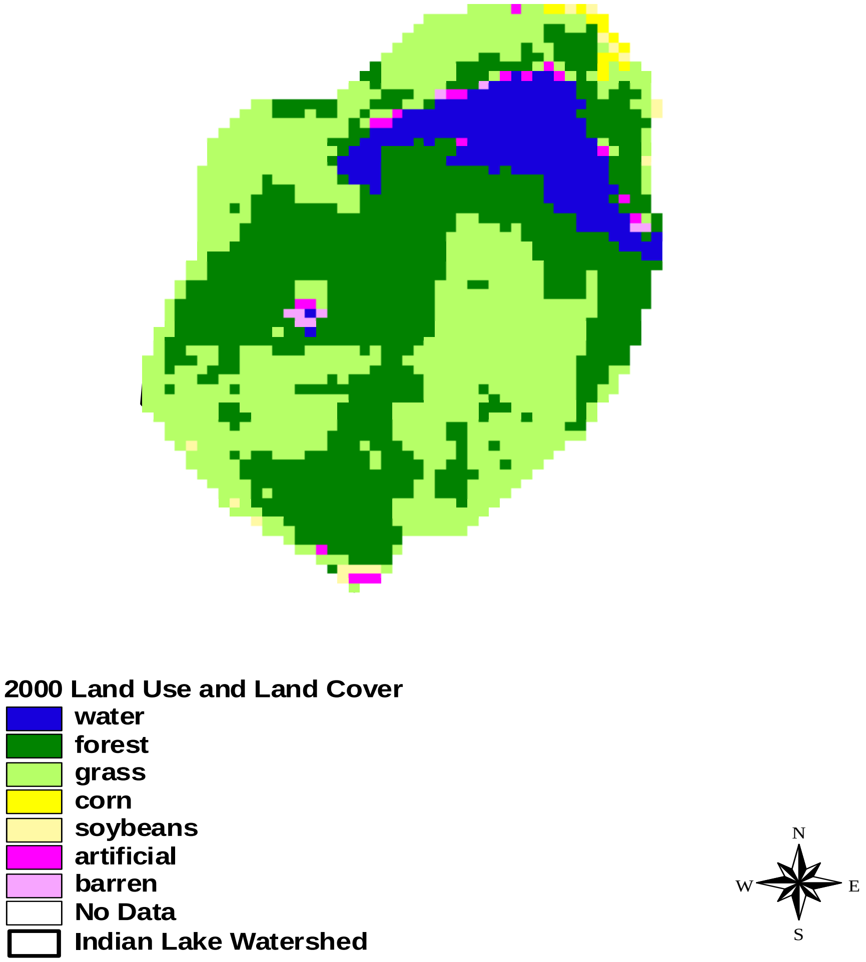
| Sample Date | TSI (SD) | TSI (CHL) | TSI (TP) |
|---|---|---|---|
| 5/18/1990 | 65 | 75 | 81 |
| 6/23/1990 | 70 | 70 | 78 |
| 7/21/1990 | 51 | 48 | 74 |

Table C-6.  2000 - 2003 Indian TSI Values (3,4,5,20)

| Sample Date | TSI (SD) | TSI (CHL) | TSI (TP) |
|---|---|---|---|
| 6/28/2000 | 63 | -- | 78 |
| 7/25/2000 | 67 | 58 | 86 |
| 8/16/2000 | 77 | 59 | 91 |
| 5/30/2001 | 44 | 37 | 63 |
| 6/26/2001 | 67 | 76 | 61 |
| 7/31/2001 | 77 | 80 | 87 |
| 6/4/2002 | 53 | 50 | 60 |
| 7/9/2002 | 73 | 82 | 78 |
| 8/6/2002 | 70 | 79 | 86 |
| 6/4/2003 | 70 | 58 | 82 |
| 7/9/2003 | 77 | -- | 83 |
| 8/6/2003 | 83 | 57 | 80 |

## 11. Appendix D - Land Use Map

# Figure D-1. Indian Lake Watershed 2000 Land Use and Land Cover



# 12. Appendix E - Indian Lake Loading Relationships

Figure E-1. Indian Lake Target Internal vs. External Load

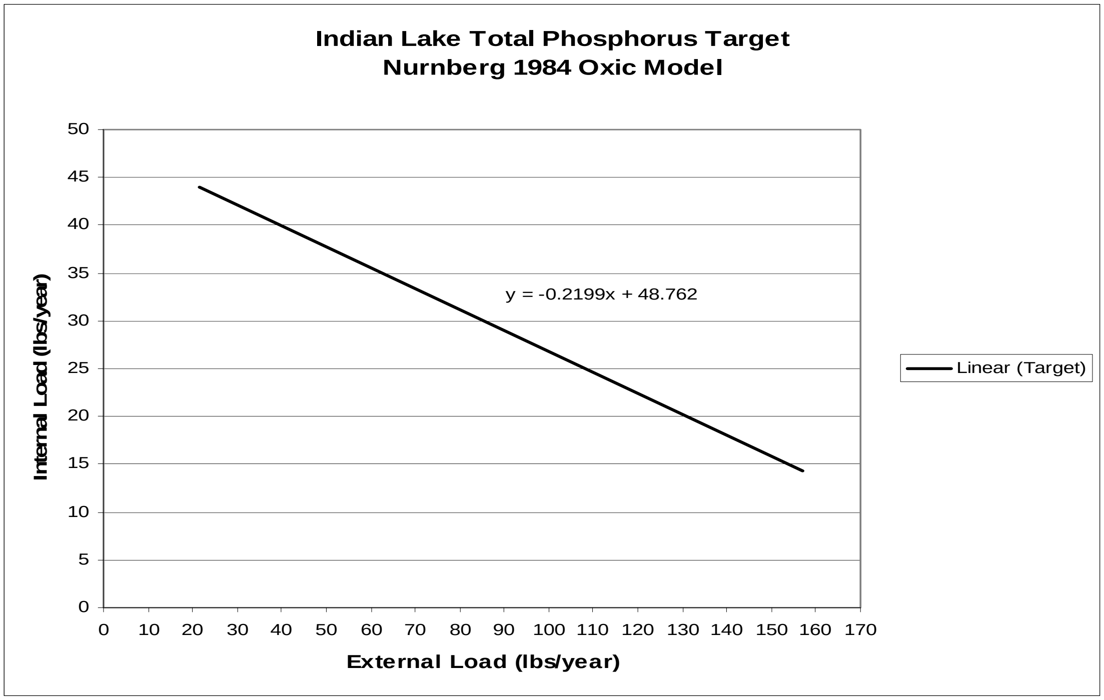


Figure E-2. Indian Lake Target Total Load vs. Internal & External Loads

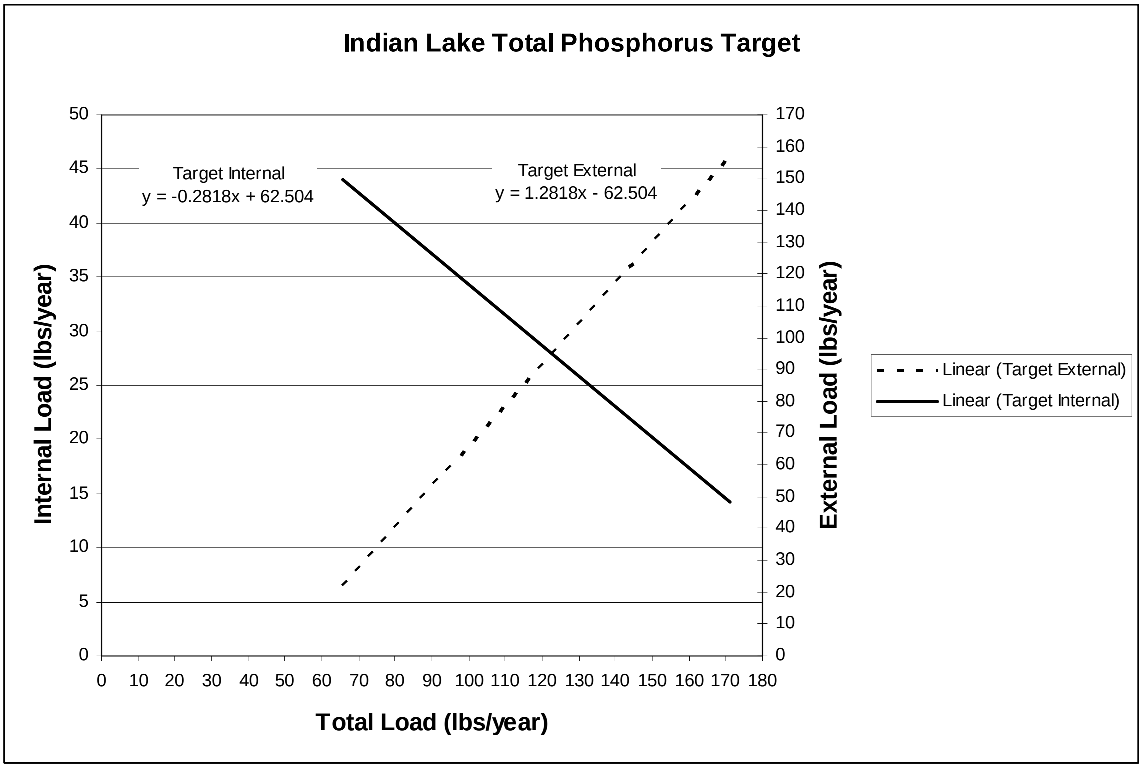


Figure E-3.  Indian Lake Load Reduction vs. Internal & External Loads